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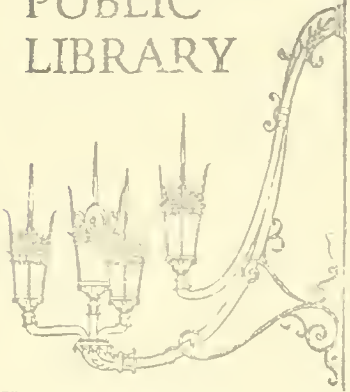

Bolt Beranek and Newman Inc.

Report No. 4470

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Experimental Study of the Air Pollution Impact of the Turnpike and Garage Ventilation Systems Proposed for the Copley Place Project, Boston, MA

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July 1980

Prepared for:
Urban Investment and Development Company

Copley Place
(Back Bay)
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Experimental Study of the Air Pollution Impact of the Turnpike and Garage Ventilation Systems Proposed for the Copley Place Project, Boston, Mass.

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July 1980

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FORWORD

This report summarizes the methods and key findings of a fluid modelling study performed in the BBN Atmospheric Boundary Layer wind tunnel to simulate the fluid dynamic dispersion of pollutants released from two large ventilation stacks associated with the proposed Copley Place project. The facility and model used were identical to that described in Appendix A of a companion report entitled "Pedestrian Wind Environment at Copley Place, Boston, Massachusetts" (BBN Report Number 4415).

The simulation of such dispersion processes involves a reasonably elaborate documentation of flow phenomena and a careful monitoring of tracer gas concentrations released into the system. The methods used for performing this work are briefly described in the report, and are consistent with those recommended in the EPA draft guideline for fluid dynamic modelling*, which is available for public inspection.

The results of this study are presented in the form of dilution factors which related to concentration of pollutants at any point outside of the stack to that in the stack. These dilution factors can then be applied to the full scale system for any pollutant emission rate from within the tunnel or garage areas. The incremental increase in the air pollution may then be added

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*Snyder, W.H. "Guidelines for Fluid Modelling of Atmospheric Dispersion" EPA-450/4-79-016 June 1979 (Draft)

to the existing or predicted background levels from other sources such as street vehicular traffic, and the hourly or eight-hour CO concentrations can be predicted and compared with standards.

I. INTRODUCTION

The Copley Place project will cover the Mass. Turnpike east and west lanes, the B & A railroad line, and several turnpike ramps. In addition, the project will contain two parking garages which must be ventilated to maintain favorable air quality within the garages. Two ventilation systems are to be operated separately using fans to push air through ventilation stacks, which are located along the south side of Stuart Street (Figure 1). The ventilation stack for turnpike ramps B and D, and the Marriott and Central garages, is located in the southeast corner of the retail area approximately at roof level (elevation 185), also shown in Figure 1. The design flow rate for these two stacks at full capacity are 1.23 million cubic feet per minute (cfm) for turnpike ventilation stack (Stack I) and 640,000 cfm for the ramp and garage ventilation stack (Stack II).

Under certain wind directions and speeds, the location of these ventilation stacks within the project elements gives rise to aerodynamic phenomena (called downwash) which cause the fumes and pollutants being ventilated through these stacks to be brought down to street level in areas near high-rise and other buildings. Likewise, the "canyoning" effect of the various streets can reduce the rate of dispersion of air pollutants from these sources below

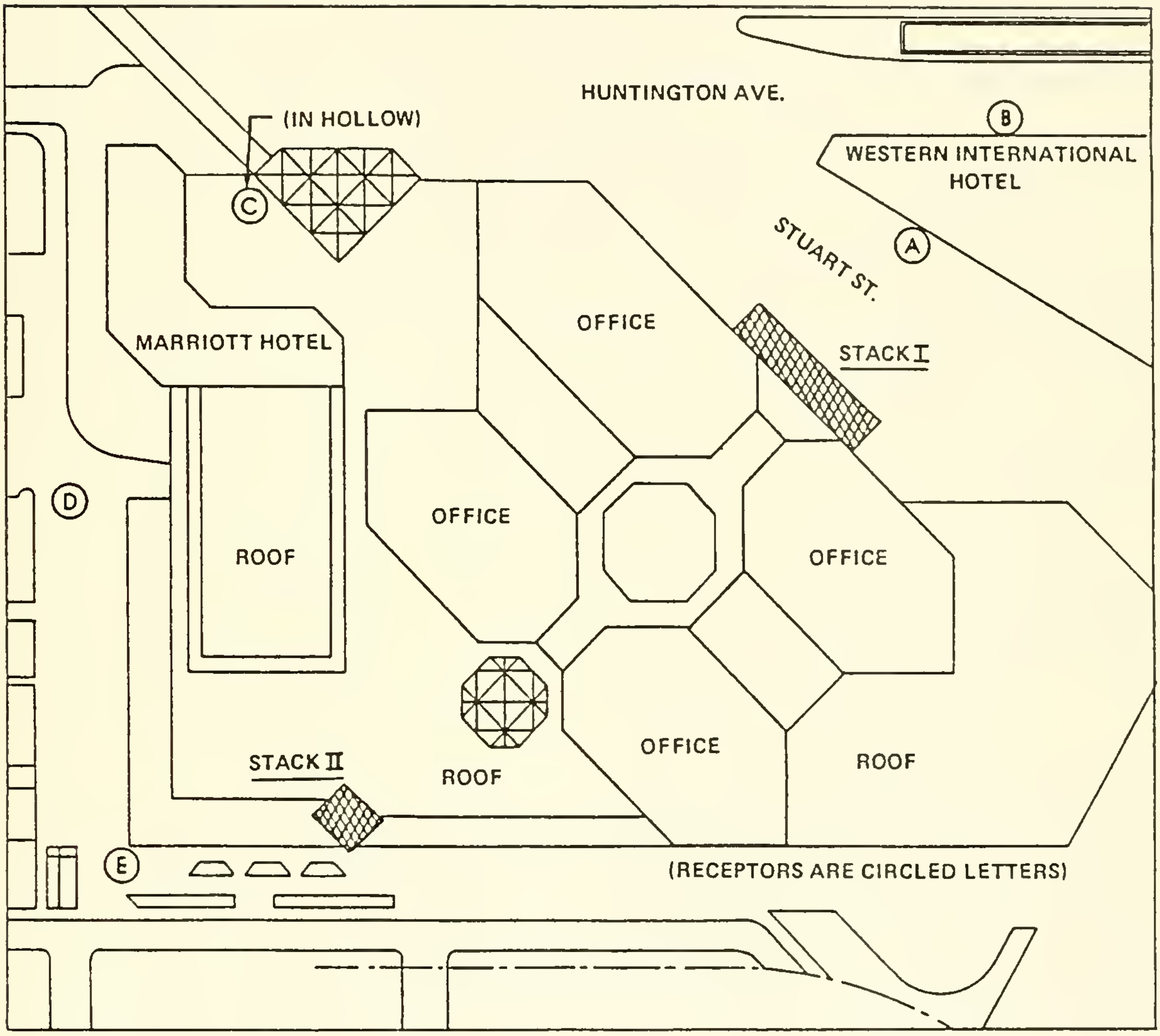

Figure 1. Location of Ventilation Stacks and Receptors Within Copley Place Site.

what it would be in the absence of large street "canyons". The ability of present day air pollution dispersion computational models to accurately predict the dispersion phenomena associated with sources released near high-rise elements or in complex street "canyons" is very limited. The consequence of the limitations of computational models may either be an over-estimate or an under-estimate of the pollution levels at various points near the Copley Place Project or similar projects. The consequence of an overestimate would lead to design of an unnecessarily elaborate and expensive ventilation system, while an underestimate of the levels could lead to localized areas of unacceptably high levels of carbon monoxide or other fumes.

Wind tunnel studies of these dispersion processes have led to improvements in the accuracy of prediction of air pollution impacts in complex urban environments. The next section of this report briefly summarizes the techniques which are used to conduct such a modelling study; Section 3 summarizes key results.

2. SUMMARY OF METHODOLOGY

The modelling of dispersion from point sources in complex environments involves:

(1) Proper simulation of the geometry of the area,

(2) The detailed correct simulation of the mean velocity profile and atmospheric turbulence characteristics incident upon the site and within the stack emitting the pollutant of interest. This simulation of turbulence and flow parameters for both the atmosphere and the source are crucial to the proper achievement of meaningful results within the wind tunnel;

(3) A simulation of both buoyancy and momentum effects within a stack. If the stack gas is"cold"and consists largely of air at ambient temperatures with small amounts of pollutants or other concentrations, then the buoyancy effects of the plume emanating from the stack are negligible and the momentum of the jet dominates the mixing of the pollutants with ambient air and thus the dispersion process.

(4) Measurement of ground level locations using a system which can resolve pollution at small points without disturbing the flow field in the neighborhood.

The methods used in the BBN atmospheric boundary layer wind tunnel for fluid dispersion modelling are consistent with those recommended by EPA in a recently proposed guideline document.* For the present study it was determined that the so-called Froude number (ratio of inertial forces to buoyant forces in a plume) would be simulated without artificially lightening the gas in the stack through the use of helium or other lighter-than-air gases. The dispersion processes are governed by turbulent mixing of the plume, which is due to the side shear layers of the plume and atmospheric turbulence. This process is quite dependent upon a dimensionless ratio of fluid inertial forces to those due to the internal viscosity of the fluid ; this parameter is known as the Reynolds Number. It is not always possible in model scale to duplicate the full scale Reynolds number to a degree sufficient to achieve identical mixing processes without artificially disturbing the flow. Thus, the flow in the jet is made to behave like a full-scale flow, i.e. one at full scale Reynolds Number,by artificially introducing turbulence in the jet through the use of screens and other flow disturbing devices. The consequence of a low Reynolds number is less turbulent mixing than that at full scale, and thus higher local concentrations

The methodology used to acquire data in the wind tunnel is now described. The system used consists of a flow mixing system

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* See earlier footnote

which supplies air to the exhause stack (or stacks), which is mixed with a tracer gas, methane (CH_4), in relatively low concentrations, such that the mass flow in the stack is dominated by the clean air system. The stack exit is calibrated to ensure uniformity of velocity profile and methane concentrations.

The wind tunnel is then operated at a variety of speeds to enable examination of the full range of dispersion parameters. Receptor nozzles consisting of small tubes anchored at various positions on the model are placed at so-called key receptor locations at various points around the site and the neighborhood adjacent to the project. These nozzles may be either sampled continuously to obtain a time history of the concentration at a given point, or by a simultaneous sampling system which acquires and holds samples from each of up to 80 nozzles simultaneously. Both capabilities of the nozzle sampling system may be useful in a project such as this. However, to enable the experimenters to quickly locate wind azimuths and receptors which may be critical to the environmental impact of the ventilation system, the receptors are operated in a continuous mode one at a time. The output of the sampling system is continuously plotted in time while the turntable holding the model is slowly rotated through 360 degrees of wind direction. A sample plot which results from this process is shown in Figure 2. The traverse rate on this plot is between one-half degree and one degree of wind azimuth.

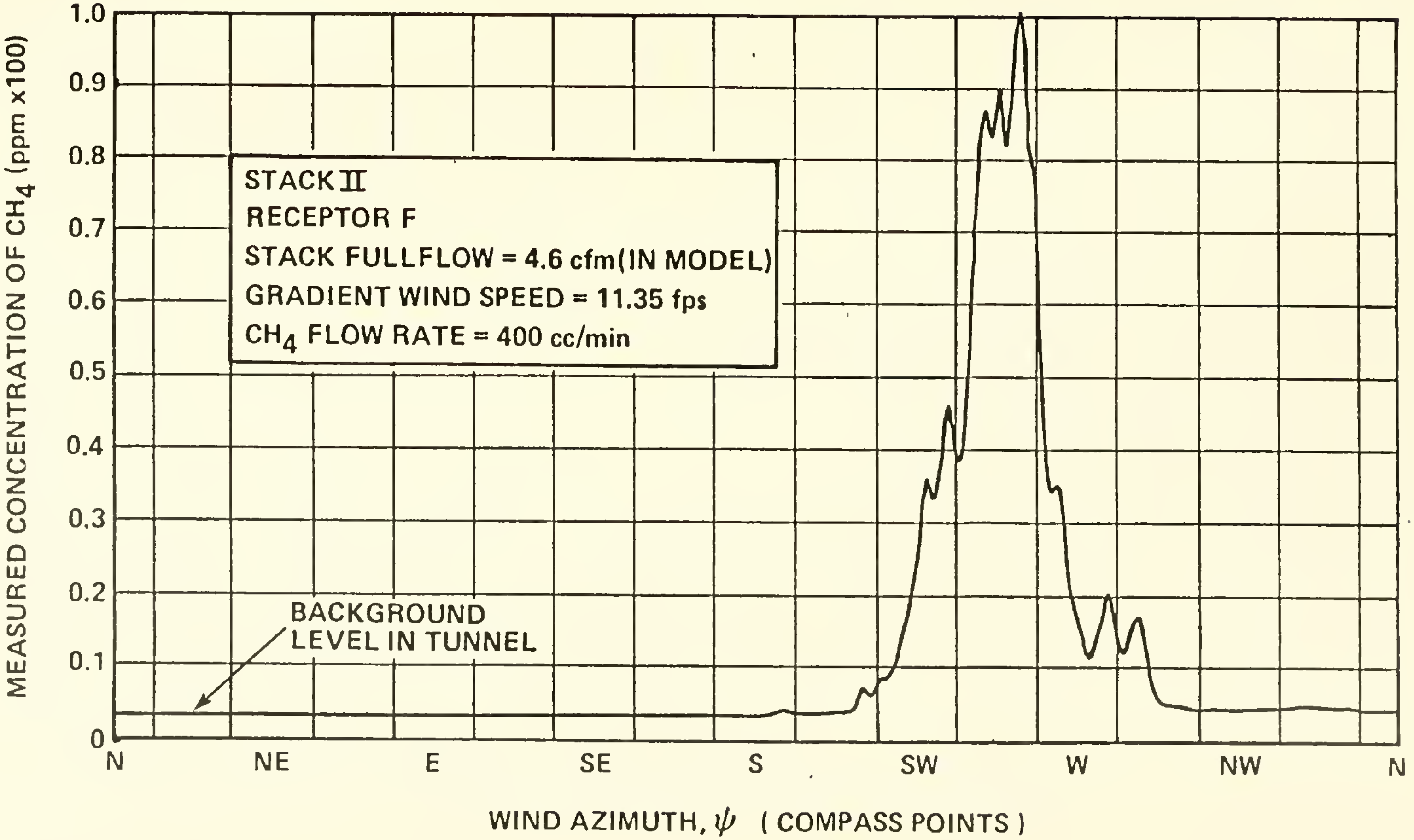

Fig. 2 Typical Wind Tunnel Data Showing Concentration at Receptor for Continuous Variation in Wind Direction (Stack Flow Held Constant)

per second. This causes some rapid fluctuation in the instantaneous concentration received at the receptor; however, these fluctuations are related to aerodynamic phenomena which are slowly changing as the model rotates and are quite typical of the actual situation to be expected at full scale.

Upon identifying the wind azimuths at which peak concentrations occur, the model is returned to those wind directions, and the nozzle is sampled for a longer period of time to measure a long-term average , and standard deviation from the average, for the flow conditions in interest. Also at this point, variations in wind velocity and stack effluent velocity are made to determine the parametric behavior of the concentration reaching a particular receptor. A sample result of those parametric variations is shown in Figure 3, for a receptor located along Stuart Street facing a low rise element of Copley Place Project, on the (north) Western International side of Stuart Street. The source of pollutant in this case is Stack II, operated at full load, 1/2 load, and 1/4 load, all of which are possible options in the operation of the actual system. It can be seen that at very low wind speeds, the plume apparently escapes any influence of the buildings and mixes with the atmosphere at very high altitudes, never reaching the ground. As the wind speed increases, the plume is bent over and impinges on the tops of buildings and, subsequently

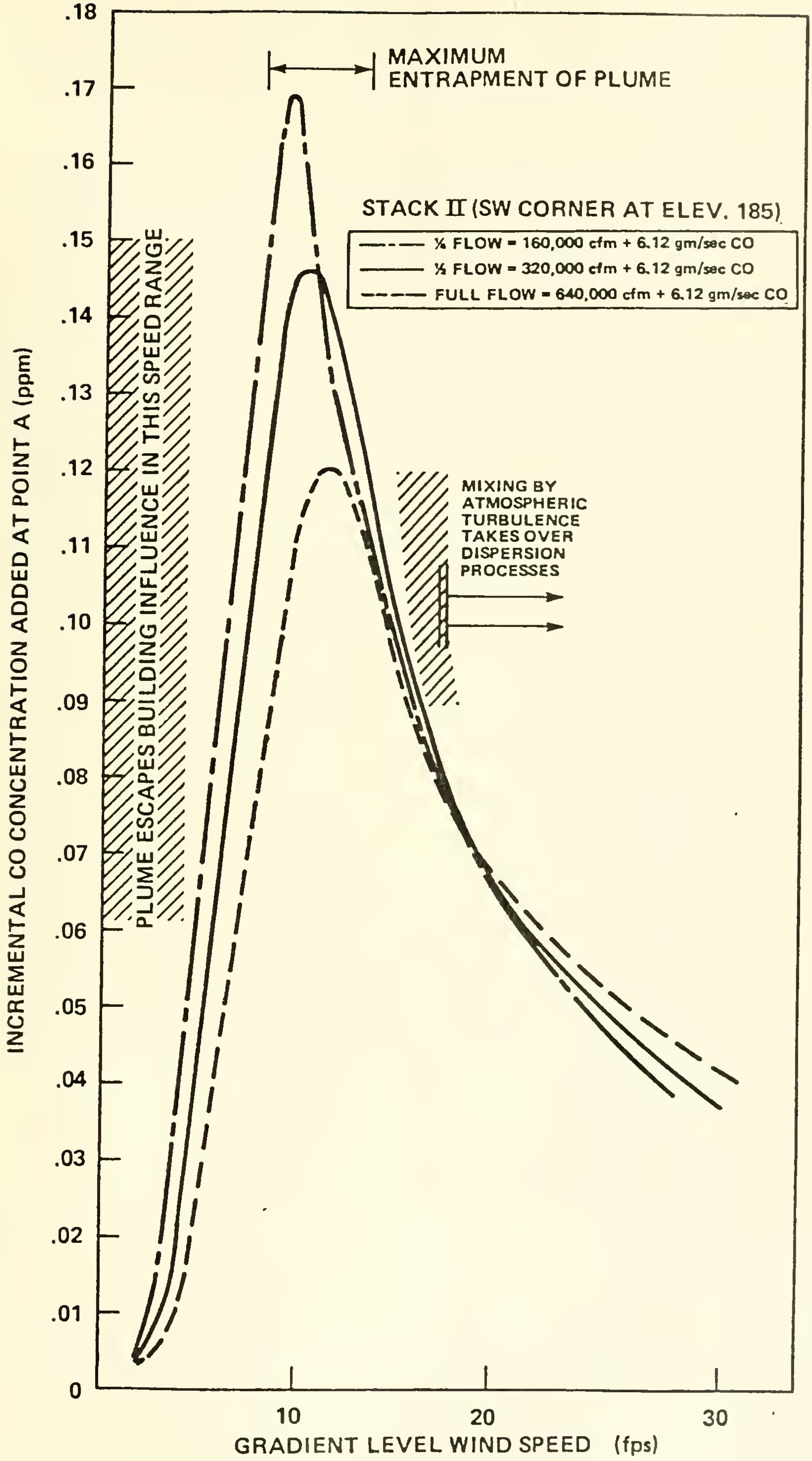

Fig. 3 Effects of Variations in Wind Speed & Stack II Volume Flow on C.O. Concentration at Receptor A

becomes entrapped in the downwash between the Western International Hotel and the low rise along Stuart Street; this entrapment leads to a peak reading on the Stuart Street side which in this case is around 0.2 parts per million of carbon monoxide, when the results are scaled to full scale conditions* It can be seen that when the system is operated at full flow, the magnitude of this peak concentration can be reduced. It is also seen that as the gradient level wind speeds increase, the atmospheric mixing processes tend to reduce the concentration of pollutant reaching the street. (The mean annual wind speed for Boston is between 28 and 30 fps at gradient height; thus, for average day conditions, the stack plumes will be well-mixed by the atmospheric winds.) Similar parametric curves are shown for receptor E, which is at the corner of the southwest corridor deck and Harcourt Streets, for the Stack II operation (Figure 4), and Receptor A when the larger Stack I is operated (Figure 5). Receptor A receives the largest concentration of ground level pollutants form the ventilation system of any examined in the entire system.

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*See Appendix A for scaling relationship

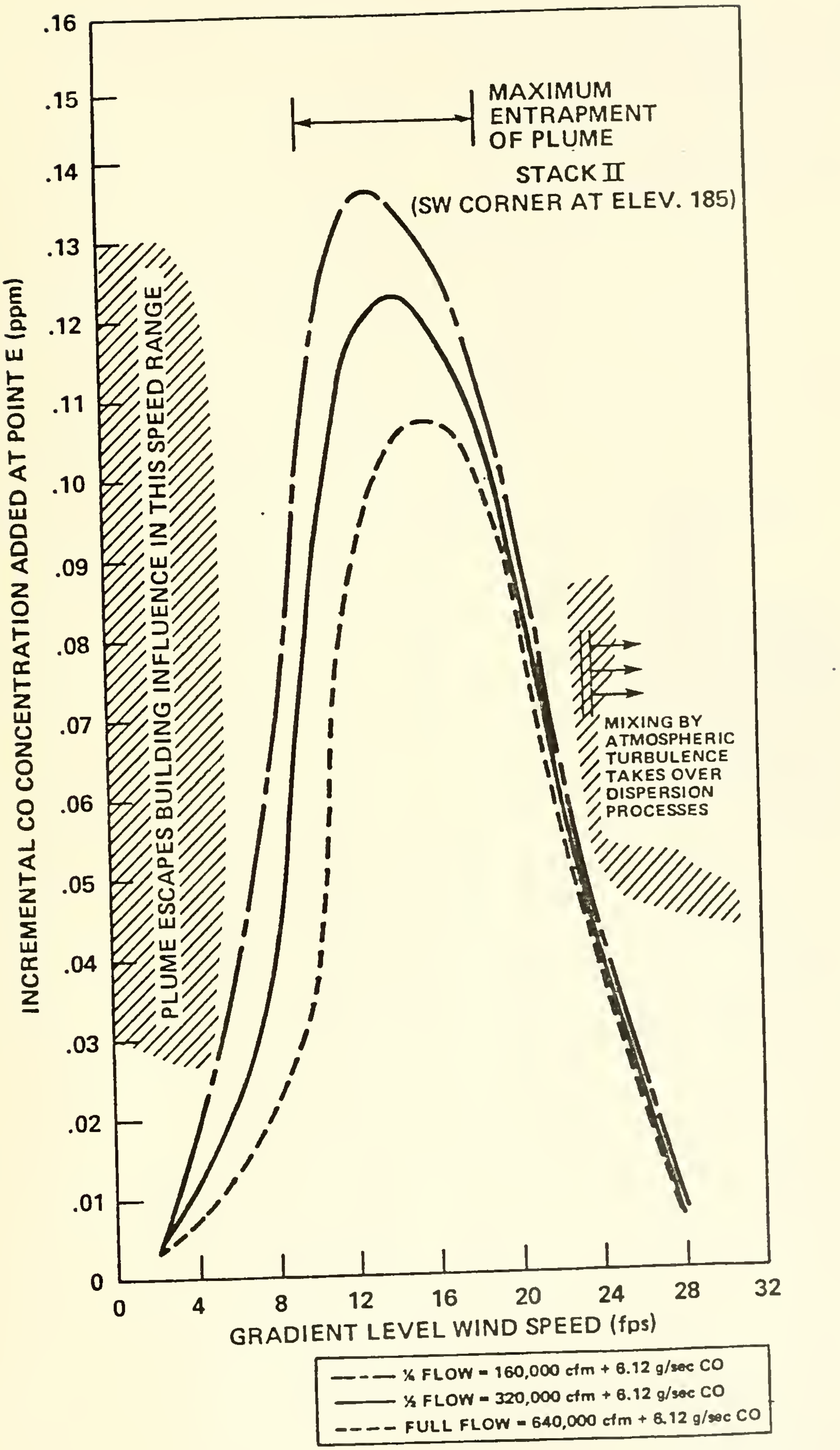

Fig. 4 Effects of Variations in Wind Speed and Stack II Volume Flow on C O Concentration at Receptor E

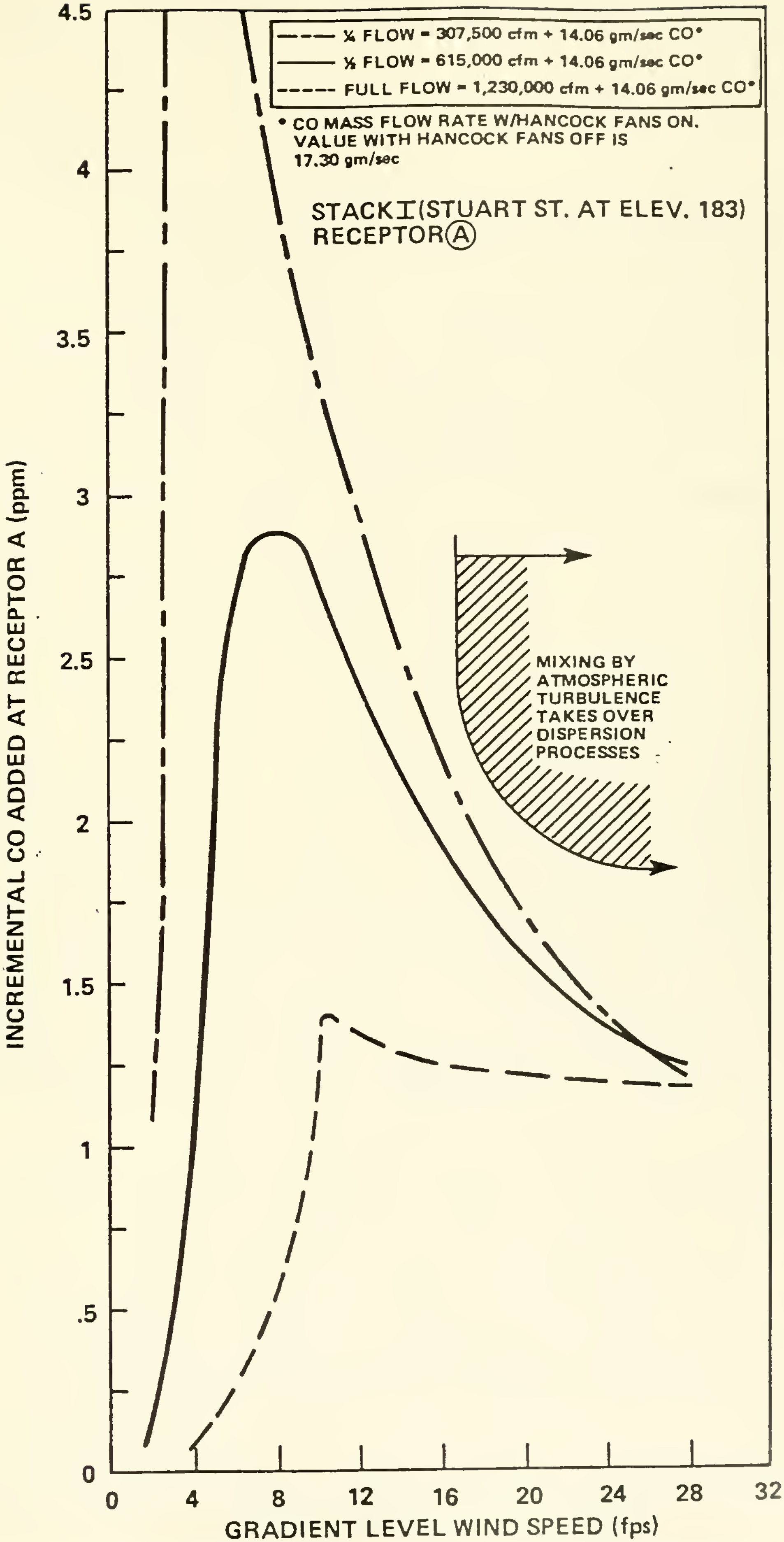

Fig. 5 Effects of Wind Speed and Stack I Flow Variations on C O Concentration at Receptor A

3. SUMMARY OF RESULTS

The results of these studies can be summarized in the form of dilution factors for the various combinations of stack flow , wind speeds, and wind directions at each receptor and can also be translated to full scale CO concentration increases (above background level) resulting from the operation of the system. Figures 1 and 6 show locations of the stacks and the 15 receptors for which data is available. As previously mentioned, data was taken at each receptor as a continuous function of wind azimuth for at least one and usually two wind speeds (11.3 fps and 28.3 fps). The speed of 11.3 fps was chosen because worst case concentrations were found around this speed in the parametric study; 28.3 fps is approximately the annual mean gradient wind speed for Boston, and is thus typical of what one would expect on a routine basis. The data reported reflects the peak values observed at any of these receptors for a complete 360 degree wind rose. The parametric trends shown in Section 2 (i.e.,Figures 3 through 5) would apply qualitatively to the data summarized in this table.

Table 1 summarizes the features of the full scale ventilation system and of the CO "source" emission rates estimated for the worst case. Table 2A summarizes the peak CO concentrations increments and the dilution factors applicable to each of the 15 receptors for the highest concentrations observed with design (full) volume flow from Stack I.

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* See Appendix A for definition.

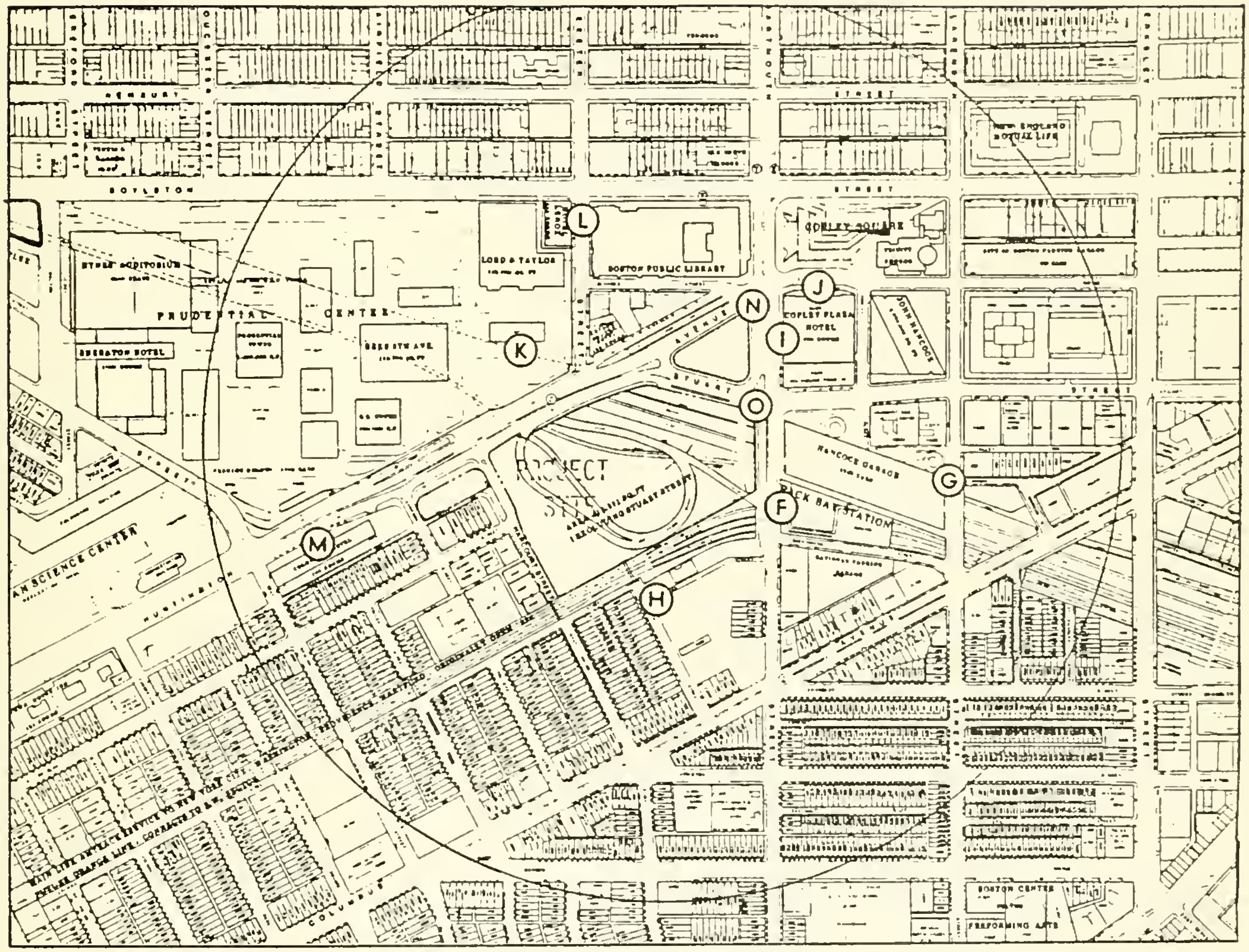

Figure 6. Receptor Locations Beyond Copley Place Site

TABLE 1

PHYSICAL DIMENSIONS AND FLOW CHARACTERISTICS FOR RAILROAD, AND PROPOSED COPLEY PLACE TURNPIKE AND GARAGE VENTILATION SYSTEMS.

Stack I (Turnpike Mainline and Railroad)

- Exit location on Stuart Street at El. 183
- 8 fans
- Full Output Volume Flow: 1.23 million cu. ft./minute
- Approximate Size of Stack Opening: 120' x 24'
- Stack Air Temperature: ambient
- CO mass emission rate for case in question:

  14.06 gm/sec (Hancock fans running)

  17.3 gm/sec (Hancock fans off)
- Corresponding CO Volume flow rate at standard conditions

  6.78×10^5 cc/min &

  8.34×10^5 cc/min

Stack II: (Turnpike Ramps & Garage)

- Located at SE corner of retail area at elevation 185
- 3 fan systems -

Ramp B and D	180,000 cfm
Central Garage	330,000 cfm
Marriott Garage	130,000 cfm
Total	640,000 cfm

- Approximate size of stack opening: 32' x 28'
- CO mass emission rate for this case:

  6.12 gm/sec (corresponding volume flow rate or 1.14×10^5 cc/min at STP)

TABLE 2A. SUMMARY OF DILUTION FACTORS AND PEAK CONCENTRATIONS AT 15 RECEPTORS FOR STACK I OPERATION*

Receptor	Wind Direction	Wind Speed (fps)	Stack Flow	Measured Dilution Factor	Full Scale CO Increase (ppm) for Source Levels Assumed in Table 1
A	SSW	11.3	Full	14.4%	2.85
A	SSW	28.3	Full	6.4%	1.27
B	S	11.3	Full	11.3%	2.23
B	S	28.3	Full	4.7%	0.93
C	ENE	11.3	Full	5.7%	1.13
C	ENE	28.3	Full	5.4%	1.07
D	NE	11.3	Full	6.1%	1.21
D	NE	28.3	Full	0.6%	0.12
E	N	11.3	Full	1.9%	0.38
E	N	28.3	Full	0.9%	0.18
F	WNW	11.3	Full	2.9%	0.57
F	WNW	28.3	Full	1.8%	0.36
G	WSW	11.3	Full	2.6%	0.51
G	WSW	28.3	Full	1.2%	0.24
H	NNW	11.3	Full	2.8%	0.55
H	NNW	28.3	Full	1.3%	0.26
I	SW	11.3	Full	3.0%	0.59
I	SW	28.3	Full	1.4%	0.28
J	SW	11.3	Full	2.4%	0.47
J	SW	28.3	Full	1.1%	0.22
K	SE	11.3	Full	13.5%	2.67
K	SE	28.3	Full	5.0%	0.99
L	SE	11.3	Full	7.3%	1.44
L	SE	28.3	Full	1.9%	0.38
M	ENE	11.3	Full	3.3%	0.65
M	ENE	28.3	Full	1.4%	0.28
N	SW	14.3	Full	1.9%	0.38
N	SW	28.0	Full	1.1%	0.22
O	NW	14.3	Full	4.6%	0.91
O	NW	28.0	Full	4.2%	0.83

*NOTES:

(1) Concentrations are the increment due to Stack I only.

(2) $\text{Dilution factor} = \frac{\text{Volume concentration at receptor}}{\text{Volume concentration in Stack}}$

(3) Full Flow = 8.2 cfm Model; 1.23M cfm Full Scale

The CO increments calculated can be viewed as valid for whatever length of time the wind conditions can be assumed as stationary in time and direction; i.e. if the wind were steady for one hour, the CO increments could be added to background levels and other sources and compared to a one-hour standard, etc. Since the peaks summarized are for the wind direction producing the worst case at each receptor, these CO concentrations could be used to product a worst-case impact in deriving either a one-hour, eight hour (or other period) air quality impact level. It is anticipated that the data supplied will be used to perform such calculations for the Copley Place EIR/EIS.

Table 2B summarizes similar results for the operation of Stack II. It can be seen that the incremental increases in carbon monoxide level,both near the site and far away,due to the operations of Stack II are small.

For those wind directions where impacts are observed at a given receptor for both Stacks I and II, the combined impact of the ventilation systems can be computed by simply adding the concentration levels observed due to each stack. If additional sources are identified within the turnpike and garage system, then the dilution factors can be used to calculate incremental impacts due to the additional source.

TABLE 2B. SUMMARY OF DILUTION FACTORS AND PEAK CONCENTRATIONS AT 15 RECEPTORS FOR STACK II OPERATION*

Receptor	Wind Direction	Wind Speed (fps)	Stack Flow	Measured Dilution Factor	Full Scale CO Increase (ppm) for Source Levels Assumed in Table 1.
A	S	11.2	Full	3.4%	.202
B	S	11.2	Full	3.4%	.202
C	ESE	11.2	Full	2.7%	.160
D	NE	11.2	Full	3.3%	.196
E	N	11.2	Full	3.3%	.196
F	WSW	11.35	Full	3.1%	.184
G	SW	11.35	Full	1.6%	.095
H	NNW	11.35	Full	2.1%	.125
I	SSW/SW	11.35	Full	1.7%	.101
J	SW	11.35	Full	1.7%	.101
K	SE	11.35	Full	1.0%	.059
L	SE	11.35	Full	1.5%	.089
M	E	11.35	Full	2.3%	.136
N	SW	11.35	Full	1.3%	.077
O	SW	11.35	Full	1.2%	.071

*NOTES: (1) Concentrations are the increment due to Stack II only

(2) Dilution factor = $\frac{\text{Volume concentrations at receptor}}{\text{Volume concentration in Stack}}$

(3) Full Flow = 4.6 cfm Model; 640K cfm Full Scale

APPENDIX A

CALCULATION OF FULL SCALE CONCENTRATION FROM MODEL SCALE DATA

Introduction

When pollutant concentrations or efflux rates are measured or quoted at either model or full scale, and then converted to the other condition, extreme care must be taken to ensure that mass concentration (or efflux) and volume concentration (or efflux) are not inadvertantly confused.

Pollutant efflux rates are usually stated in grams/second, a mass-based parameter, while air quality standards are usually written in terms of volume concentration; i.e., parts-per-million (ppm).

A detailed discussion of the general conversions involved in fluid modelling may be found on p. 141 of Synder's EPA Draft "Guideline for Fluid Modelling of Atmospheric Diffusion" EPA-450/4-79-016 (June, 1979).

Concentration Ratios:

The ratio of mass concentration, C, in full scale (subscript f) to that at model scale (subscript m) is:

$$\frac{C_f}{C_m} = \left(\frac{U_m}{U_f}\right) \left(\frac{H_m}{H_f}\right)^2 \left(\frac{M_f}{M_m}\right) \tag{A.1}$$

where U = gradient wind speed

H = typical length dimension $\frac{H_m}{H_f}$ = scale factor

M = mass flow rate of pollutant (typically in gm/sec)

The volume concentration χ ratio is simply

$$\frac{\chi_f}{\chi_m} = \frac{C_f}{\rho_f} \Bigg/ \frac{C_m}{\rho_m} \qquad (A.2)$$

where ρ = the fluid density of the full scale or model scale pollutants or tracer gases respectively.

The mass flow rate M is simply ρQ, where Q is the volume flow rate of a particular pollutant. In the case studied, the respective gases are both at ambient termperature for both the model and full/scale conditions; thus,

$$\frac{\chi_f}{\chi_M} = \frac{U_m}{U_f} \frac{Q_f}{Q_m} \left(\frac{H_m}{H_f}\right)^2 \qquad (A.3)$$

In the modelling conducted in this study, $U_m = U_f$, and $H_m / H_f = 1/384$; therefore Eq. A.3 simply becomes

$$\chi_f = \chi_m \quad (6.78 \times 10^{-6}) \times \frac{Q_f}{Q_m}$$

where χ_m = the measured CH_4 concentration in ppm, and

$Q_{f_I} = 6.78 \times 10^5$ cc/min of CO for Stack I at full flow;

$Q_{f_{II}} = 1.14 \times 10^5$ cc/min of CO for Stack II at full flow,

Q_m ranged between 200 and 800 cc/min in the model tests, depending upon the particular test, but 200 cc/min was used most often for the data quoted earlier. Thus, for example,

$\chi_f = 2.3 \times 10^{-2}\ \chi_m$ for Stack I with 200 cc/min of tracer flowing in the model.

Dilution Factor

The dilution factor is a convenient aid to understanding the relative diffusion of pollutants from a source (such as a ventilation stack) to remote receptors. The dilution factor (DF) is defined here as:

$$DF = \frac{\chi_{measured} - \chi_{background}}{\chi_{stack} - \chi_{background}}$$

When the gas and surrounding air temperatures are equal at ambient temperature, in the model,

$$\text{and } \chi_{stack} = \frac{Q_{CH_4}}{Q_{air}} ;$$

where Q_{air} is the total stack volume flor rate.

The provide a numerical illustration, the stack flow for Stack I was 8.2 cfm (2.32×10^5 cc/min) in the model and the tracer flow rate was 800 cc/min; thus $\chi_{stack} = 3.45 \times 10^{-3}$ (or 3445 ppm) in this case. If the measured concentration at a given receptor s 100 ppm and the background concentration in the tunnel was 5 ppm, then $DF = \frac{100-5}{3440-5} \approx 0.0276$, or 2.76% at that receptor.

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